Power Engineering

An On-Site Process for Removing Moisture from Low-Rank Coal

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Lower-than-design heating value of delivered coal can result in higher fuel flow rate, higher flue gas flow rate, higher station service power, lower plant efficiency and higher mill and coal pipe/burner operations and maintenance costs, plus a host of lesser effects.

Commissioned in 1979 and 1981, Coal Creek Station near Underwood, N.D. includes two 600 MWg mine-mouth, lignite-fired natural circulation units with tangentially-fired, dual-furnace boilers with eight pulverizers each. Both units were installed with wet scrubbers as original equipment. Great River Energy, an electric cooperative owned by 28 members and serving 1.7 million customers in Minnesota and Wisconsin, owns and operates Coal Creek, as well as nine other power plants with a total output of more than 2,500 MW. Fuel for Coal Creek is provided by North American Coal Corp.'s Falkirk Mine near the plant.

Coal Creek's design performance was based on an original fuel heating value specification of 6,800 Btu/lb. However, the heating value of the fuel being delivered to the plant has only been about 6,100 to 6,200 Btu/lb. The major effect of this 10 percent shortfall in heating value has been reduced boiler thermal efficiency, lost pulverizer selection flexibility, increased volumetric flue gas flow and increased station service power requirements. The reduced heating value is caused by increased moisture and ash in the coal. At Coal Creek, the plant design fuel had a moisture content of about 36.6 percent and an ash content of 6.2 percent. The delivered fuel is around 38 percent moisture and 10.9 percent ash.

During the 1990's, the plant's engineering staff began investigating options for meeting future emission regulations. Conventional techniques involved changing fuels and/or adding environmental control equipment. But these approaches often result in cutting emissions at the expense of increases in unit heat rate and operating and maintenance costs. Higher heat rate results in higher required fuel heat input, higher CO_2 emissions, higher flow rate of flue gas leaving the boiler and lower net plant capacity resulting from higher station service power requirements or equipment capacity limitations. Further, the increased flue gas flow rate leads to larger-sized environmental control equipment, plus higher equipment cost and station service power. As many of these same factors would be fundamentally improved by restoring the performance lost to the reduced fuel HHV situation, Coal Creek's plant staff elected to pursue a different course of action.

Developing DryFining

Given the potential dual benefits of recovering lost performance and reducing emissions, a decision was made in 1997 to address the low heating value problem at its root cause. With the ongoing assistance of Lehigh University's Energy Research Center and the Electric Power Research Institute (EPRI), an approach was selected using waste heat sources available in the plant to dry the incoming fuel stream using a fluid bed dryer prior to bunkering. This program, termed the Lignite Fuel Enhancement System, led to the development of Great River Energy's patented and trademarked "DryFining" process. Development was executed in three stages: a feasibility stage, a prototyping stage (Phase One) and a scale up stage (Phase Two).

The feasibility stage consisted of a "proof of concept" demonstration. A two-ton-per-hour fluid bed pilot plant was built in the Coal Creek Station coal yard with the support of the Lignite Energy Council and North Dakota Industrial Commission. Testing confirmed the dryer would dry fuel as required. Further, taking advantage of the inherent characteristic of bed fluidization to naturally segregate free material by density, it also selectively removed heavier ash components, most notably iron sulfide (pyrite). This segregation of sulfur-bearing minerals offered Great River Energy the potential benefit of removing a significant proportion of sulfur from the fuel stream prior to its entering the boiler. This benefit subsequently was confirmed in Phase Two. A similar segregation of mercury-bearing minerals also was noted. As a scrubbed facility and faced with substantial capital expenditures to meet pending stringent sulfur and mercury emissions targets, this segregation benefit offered Great River Energy an attractive alternative for emissions compliance.

Phase One drew on the pilot plant testing program to confirm the drying process. At the heart of this process was a nominal 75 ton/hr fully instrumented, low-temperature, prototype fluidized bed dryer (FBD) developed by a team of industry participants led by Great River Energy. As part of this developmental process, Great River Energy obtained funding from the U.S. Department of Energy (DOE) as a participant in the first round of DOE's Clean Coal Power Initiative (CCPI) in 2003. The Coal Creek CCPI project was administered by DOE's Office of Fossil Energy and managed by the National Energy Technology Laboratory (NETL). The prototype was integrated into Unit 2 at Coal Creek Station by effectively converting pulverizer 26 to 100 percent dried fuel. It operated almost continuously over a range of conditions from 2006 to summer 2009. During this period, the prototype FBD has processed more than 650,000 tons of coal at throughputs as high as 105 tons/hr. The prototype confirmed the capability of the full-scale dryer to reduce fuel moisture to the levels desired. Just as significantly for Great River Energy, the prototype confirmed the segregation effects observed during pilot testing translated to the full-scale device. The target performance parameters and results from the prototype testing program are summarized in Table 1.

TABLE 1 PROTOTYPE PERFORMANCE

Parameter	Prototype Feed In	Prototype Feed Out	Change
Prototype Feed Rate (tons/hr)	75		
Moisture	37.06%	28.98%	21.8%
HHV (BTU/Lb)	6,299	7,026	727
Sulfur Reduction due to segregation		-27.7%	
Mercury Reduction due to segregation		-31.3%	

The total expected reduction in sulfur and mercury emissions for the fully configured commercial coal drying system at Coal Creek Station will equal the combination of the outright reduction in fuel flow into the plant as a result of improved efficiency coupled with the sulfur removed in the reject stream that results from the segregation process. This flow of high-density, high-ash material from the bottom of the dryer was sampled and returned to the fuel stream on the prototype system to reduce the prototype cost. On the full-scale commercial system it is discharged to the ash system. This stream is analogous to the material that should be removed through the pyrite reject process at the pulverizers but at a much higher removal rate. This is because the fuel's residence time in the dryers is much longer (measured in minutes) compared to the fuel residence time in the pulverizers (measured in seconds). This results in much more complete material segregation. As a large proportion of the sulfur in Coal Creek's coal is pyritic in form and readily segregates, the sulfur content of the reject stream is significantly higher compared to the product stream.

Commercial Application

Following successful completion of Phase One and prototype evaluation, Great River Energy and the DOE agreed to proceed with the Phase Two full-scale demonstration of the drying system on Unit 2 at Coal Creek in 2006.

The prototype's promising results led the Board of Great River Energy to direct that the DryFining system be installed on both Coal Creek units. To a large extent, this decision was driven by the prospects of large offsets in capital expenditures for additions to the flue gas de-sulfurization systems, for mercury control and for NO_X emissions curtailment. DryFining proved to be the most economical solution for achieving long-term environmental compliance. It offered an opportunity to combine environmental improvement, heat rate improvement, operational improvement and expense reduction in one package. Rather than increasing the plant's O&M budget to achieve the environmental improvements, the plant estimated more than $30 million a year in expense reductions from fuel, auxiliary power and consumables.

Design throughput of the full-scale system is 3.75 million tons/year of coal, sufficient to meet 100 percent of Unit 2's needs. Four full-scale dryers, similar in design to the prototype, provide the necessary throughput with conservative redundancy. In accordance with the Board's directive, four additional coal dryers were installed on Unit 1 concurrent with the Unit 2 installation. Modification and commissioning of both units was completed in late 2009.

The performance parameters noted in Table 1 focus only on the prototype. The full-size scale-up will result in systemic improvements in the area of fuel handling, mill operation, combustion, maintenance practices, auxiliary equipment performance and emissions. For example, by reducing the overall fuel flow to the boilers by 13 to14 percent, at least one less pulverizer will have to be in operation to reach full load. This restores the flexibility to schedule pulverizer maintenance outages without risk of limiting unit output. Further, a high proportion of Coal Creek's combustion air flow is used as primary air to operate the pulverizers at required coal throughputs. This proportion will be substantially reduced with dryer fuel. As a result, internal pulverizer erosion, coal conduit erosion, coal conduit air flow distribution differential and fuel flow distribution differential all will be reduced. Also, increased secondary air flow will add flexibility for combustion and over fire air tuning.

From Great River Energy's perspective, the greatest benefits accrue from emission reductions. The slip stream testing of the prototype's rejects flow confirmed that a high proportion of pyritic sulfur can be removed in this manner. As this sulfur form composes nearly 30 percent of the overall sulfur content of Coal Creek's fuel, expectations are that the sulfur reduction associated with the drying process will approach this value. The reduction in sulfur associated with the reduced fuel flow into the plant (due to improvement in boiler efficiency) strongly suggests that overall SO_2 reduction in the flue gas exiting the boiler will be 40 percent. Similarly, examination of the rejects stream also indicated it was enriched in mercury. This had been noted during the initial pilot stage. Based on the mercury concentrations noted in the reject stream analysis, about 40 percent of the incoming mercury is projected to be removed prior to combustion.

Because it was a single device demonstrator, no formal systematic evaluation of NO_X emissions was made during the prototype test program. However, plant continuous emissions monitoring system (CEMS) output shows a sustained reduction in NO_X during the test period, as had been suspected. The post-modification testing scheduled for spring 2010 will specifically examine and quantify NO_X emissions for the full-scale application. Projections from the CEMS data lead Great River Energy to believe a 20 percent reduction in NO_X will result from the full-scale modification.

Like other utilities, Great River Energy is sensitive to CO_2 emissions concerns. The reduction in CO_2 mass emissions is proportional to the improvement in unit efficiency. For the prototype coal drying system operating at target moisture reduction of 8.5 percent points, this reduction, based purely on direct thermal efficiency improvement, projects to approximately 2 percent. However, due to the unique method of heat integration associated with the full-scale process, a reduction closer to 4 percent is expected. Evaluations completed for other locations parallel this projection. Clearly, knowledge of heat source integration options, along with precise and well-defined coal characteristics, is fundamental to optimizing DryFining for specific facilities.

The DryFining systems on both units at Coal Creek have been in continuous service since completing their 24-hour commercialization runs in December 2009. Post-installation performance testing will be completed in spring 2010. Initial results have been promising.

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Charles Bullinger has held various positions at Coal Creek Station since 1977, having led the engineering group there for 15 years. He organized and led a team that developed DryFining and is the primary contact and project manager for the DOE Round 1 Clean Coal Power Initiative. Presently assisting WorleyParsons in the commercialization and licensing of DryFining, Charles is a registered professional engineer in North Dakota and Minnesota.

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